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EFFECT OF METAL DESIGN AND TECHNIQUE ON THE MARGINAL CHARACTERISTICS OF THE COLLARLESS METAL-CERAMIC RESTORATION

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In 1983 Prince, Donovan, and Presswood described a method of fabricating collarless metal-ceramic restorations using synthetic wax as the binder for establishing the porcelain margin. Schrader et al. (1986) demonstrated the porcelain/wax technique resulted in 11.4% less shrinkage than a conventional liquid/porcelain technique. Gordner (1986) determined the decrease in porcelain shrinkage attained was due to an increase in porosity. As the ratio of porcelain to wax was increased, the shrinkage percentage, apparent specific gravity, and transverse rupture strength were decreased.

When comparing porcelain/wax, direct-lift, and platinum foil techniques for margin fabrication, Cooney et al. (1985)

found those produced by the porcelain/wax method yielded the poorest marginal adaptation. They stated modification of coping design and technique application might improve their results.

The purposes of this investigation are to: (1) examine how the marginal characteristics of restorations fabricated with a porcelain/wax technique differ from those of a porcelain/liquid technique; (2) determine if metal coping design has any influence on marginal characteristics; and (3) evaluate the effect of labial margin fabrication on lingual margin adaptation.

Uniformly prepared collarless metal-ceramic restorations were fabricated with porcelain/liquid and porcelain/wax techniques. Two different metal coping marginal designs were employed to comprise four experimental groups. Each group contained 15 specimens for a total of 60 samples. External marginal openings were recorded on sectioned specimens on both the facial and lingual surfaces. In addition, the mean marginal opening was recorded between the porcelain margin and the shoulder of the die along the first 750 microns from the external margin.

Statistical analysis of the data revealed the following:

1. The porcelain/liquid groups demonstrated significantly smaller facial marginal openings than the porcelain/wax groups.

2. The porcelain/wax technique produced margins which were rounded over their external 100 microns.

3. The group fabricated with the porcelain/liquid technique with the metal on the die shoulder produced the most consistent overall results.

4. The porcelain/liquid group with the metal off the shoulder of the die had a statistically larger mean marginal opening from 0.25 mm to 0.75 mm on the internal aspect of the shoulder than the other three groups.

5. The porcelain/liquid group with the metal off the shoulder of the die had a statistically larger mean marginal opening from the external margin to 0.75 mm interior than both techniques with the metal to the shoulder.

6. Lingual marginal adaptation did not vary with each of the four experimental groups.

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EFFECT OF METAL DESIGN AND TECHNIQUE
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COLLARLESS METAL-CERAMIC RESTORATION

A

THESIS

Presented to the Faculty of

The University of Texas Graduate School of Biomedical Sciences

at San Antonio

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Donald M. Belles, B.A., D.D.S.

San Antonio, Texas

May, 1987

EFFECT OF METAL DESIGN AND TECHNIQUE ON THE MARGINAL CHARACTERISTICS OF THE COLLARLESS METAL-CERAMIC RESTORATION

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DEDICATION

To Ivy: proofreader; typist; editor; motivator; friend;
and the world's best wife.

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I. INTRODUCTION

The concept of the metal-ceramic restoration dates back to the nineteenth century. In an attempt to prevent the slumping of porcelain jacket crowns during firing, Land (1886) used a swaged platinum reinforcement for his porcelain restorations. The metal he chose was capable of forming a bond with porcelain and a crude precursor of the metal-ceramic restoration came into being. Due to the unmasked metal backing, the porcelain had a gray appearance, and the esthetic effect was poor. Since the metal was difficult to handle, a removable platinum foil matrix was then used (Land, 1903). The porcelain jacket crown was thus developed from the metal-ceramic restoration.

Brecker, in 1956, introduced the modern concept of the metal-ceramic crown to the dental profession, and since that time it has become one of the most widely used restorations in dentistry. Clinical practice and scientific studies have led to improvements in techniques and materials that have resulted in restorations of great strength with esthetic qualities impossible to achieve previously. One problem that has persisted, though, is the achievement of excellent esthetics at the labial gingival margin.

An optimal design would be esthetic, exhibit excellent margin closure, and present materials at the gingival margin that resist the adsorption of dental plaque (Donovan and

1

Prince, 1985). Most margin configurations, unfortunately, do not meet all these requirements.

The demand for high esthetic quality in the area of the labial margin combined with the strength of conventional metal-ceramic restorations may explain the increasing popularity of the collarless metal-ceramic restoration (Prince and Donovan, 1983). The porcelain labial margin eliminates the unsightly metal collar. Due to an increase of gingival porcelain at the margin, restoration of the original shade is excellent. Plaque retention may be minimized by having only highly glazed shoulder porcelain at the margins. Periodontal health is further promoted by minimal extension into the gingival sulcus because it is not necessary to hide a metal collar (Newcomb, 1974).

In an attempt to simplify these restorations, several techniques have evolved over the years. A recent technique introduced by Prince et al. (1983) uses wax as a binder for the porcelain powder. The use of a wax suspension allows a more consistent separation of condensed porcelain from the die material. It also enhances flowing wax and porcelain into the small marginal gap that results from shrinkage in the original firing.

In 1986, Schrader et al. found that there was 11.4% less shrinkage with the porcelain/wax method than with the conventional porcelain/liquid technique. This finding would support the use of the porcelain/wax technique for marginal areas. Gordner (1986) has recently demonstrated the decrease

in porcelain shrinkage attained with the wax technique is due to an increase in porosity. As the ratio of porcelain to wax increases, the shrinkage percentage, apparent specific gravity, and transverse rupture strength decreases. He recommended the use of a porcelain/wax technique only in limited situations and then with a ratio of 6:1 by weight.

When comparing porcelain/wax, direct-lift, and platinum foil techniques for margin fabrication, Cooney et al. (1985) found that those produced by the porcelain/wax technique yielded the poorest marginal adaptation. The authors felt modification of coping design and technique application could probably improve their results.

The purpose of this study was to compare the marginal characteristics of the collarless metal-ceramic restoration fabricated with a conventional porcelain/liquid technique to those fabricated with a porcelain/wax technique. Two groups of standardized metal copings varying only in their labial metal design were evaluated in regard to their influence on the porcelain margin characteristics.

This study addresses the questions:

1. Can the porcelain/wax technique yield consistently acceptable results?

2. Does the marginal character of the porcelain/wax technique differ from that of the porcelain/liquid?

3. Does the change of metal design from one brought down to the shoulder to one left 0.5 mm short have any influence on the marginal characteristics?

4. Does the porcelain/wax technique allow for better adaptation of the restoration to the die shoulder than the porcelain/liquid technique?

5. Can lingual metal coping margin adaptation be preserved during fabrication of the all-porcelain labial margin?

II. LITERATURE REVIEW

A. Margin Placement

Frequently entered but rarely understood, the gingival crevice remains an enigma to most restorative dentists. The great majority of dental restorations with margins placed in the crevice are surrounded by tissue which is inflamed, has undergone recession, or demonstrates reduced resistance to probing (Wilson and Maynard, 1981). In restorative dentistry, the margin of preference is the supragingival margin (Maynard and Wilson, 1979). It facilitates impression making, is easily finished, and is accessible to cleansing. There are, however, legitimate indications for extending a margin into the gingival crevice. Among the most frequently cited are: esthetics; the removal of caries or existing restorations; obtaining additional retention; and restoration of the fractured tooth.

One of the most widely used restorations in restorative dentistry is the metal-ceramic crown. Its virtue lies in the fact that it combines the esthetics of porcelain with the strength of a metal substructure. From an esthetic viewpoint, the presence of a metal collar is often a problem when used on anterior restorations. The collar dictates placing the margin intracrevicularly to hide the metal and make the restoration as natural as possible. Many patients possess thin, friable tissues. A metal collar beneath the gingiva

imparts a blue-gray appearance to the tissue. The problems with intracrevicular margins have been demonstrated by many dental clinicians and researchers.

In 1891 G. V. Black proposed the concept of "extension for prevention" or the removal of the enamel margin by cutting from a point of greater liability to a point of lesser liability to recurrence of caries. The concept of the subgingival margin was a natural outgrowth of Black's axiom. As early as 1941, Orban proposed supragingival margins for improved periodontal health. Orban discovered that the caries free or subgingival zone, which had been observed previously on extracted teeth, was nothing more than the location of the epithelial attachment. This epithelial attachment would not attach to the margin of a cast restoration, thus the concept of routine subgingival margins was questioned as more scientific evidence appeared.

Zander (1958) proposed that irregularities in the cervical areas of restorations act as foci allowing plaque to form in the proximity of the gingiva. These defects, promoting the formation of plaque, together with the subgingival location of the margin, do not allow self-cleansing mechanisms to operate. Waerhaug's (1956) research supported the concept of plaque foci in demonstrating that epithelial cells of the gingival margin can adapt themselves to irregularities in the surface of the restoration provided it is clean and free of a bacterial coating.

In an article on complete crown form and the periodontium, Wheeler (1961) noted that the traditional view was always

to place crown margins "beneath the gums." He considered that in a biologic approach, however, the margins may be placed at any level that will perfect the form and preserve the periodontal attachment. The location of the crown margins should be decided by a logical approach to diagnosis and prognosis and not by taking a traditional design for granted.

Loe (1968) uncompromisingly stated the extension of restorations into the gingival crevice was one of the major contributing factors in the destruction of the periodontium and that the theoretical basis for "extension for prevention" was no longer valid. He felt that efforts should be made to form a new theoretical basis for the combined prophylactic treatment of the two major dental diseases: caries and periodontal disease.

Marcum (1967) demonstrated that crowns with subgingival restorations were associated with slight to severe inflammation when examined histologically. Larato (1969) reported on an examination of the gingiva around 546 three-quarter and complete cast crowns. Greater inflammation was found around those crowns finished beneath the gingival margin than those finished level with, or above it, the later showing the inflammation least of all.

Silness in a series of articles (1970a, 1970b and 1970c) examined periodontal conditions in patients treated with dental bridges. He found that supragingivally-placed crowns caused the least damage to the gingiva, while those at or below the gingival margin were associated with significantly more

inflammation. Bjorn et al. (1969) demonstrated that subgingival marginal discrepancies greater than 200 microns can result in significant bone resorption.

Mannerberg (1971), in a series of 13 patients, constructed porcelain jacket crowns for central or lateral incisor teeth with margins placed approximately half the depth of the gingival sulcus. A greater volume of gingival exudate from around each crowned tooth was recorded than from its uncrowned contralateral tooth. Mannerberg concluded that this increase in exudate, being a measure of the inflammatory reaction present, would remain constant even if the oral hygiene was good.

Eissmann et al. (1971) stated the most important factor in successful margins was their ability to minimize plaque retention. Waerhaug (1975) proceeded to demonstrate that nine out of ten subgingival restorations were covered with plaque. He also showed that this could occur in as little as six weeks.

Richter and Ueno (1973) attempted to overcome the difficulties of looking at contralateral teeth by placing crown margins both above and below the free gingival margin on the same tooth. They used the first permanent molar in each case and constructed 12 crowns which they checked at yearly intervals over 3 years. The gingival index of three crowns in areas with subgingival margins increased in inflammation; however, it was not found to be statistically significant to the supragingival areas.

Newcomb (1974) found a very strong negative correlation between gingival inflammation and the distance of the crown margin from the base of the crevice. The nearer a subgingival margin approaches the base of the gingival crevice, the more likely that severe gingival inflammation will occur. The least inflammation was observed when subgingival crown margins were placed at the gingival crest or just into the gingival crevice. This is in agreement with Maynard and Wilson (1979) who demonstrated that subgingival margins which encroach upon the biologic width or physiologic dimension can lead to periodontal recession, inflammation, and pocketing.

Mormann et al. (1974) found a gingival fluid flow rate to be significantly higher adjacent to both the rough and polished restoration surfaces when compared with proximal surfaces without restorations. They concluded that even perfectly adapted and well polished proximal gold inlays facilitate gingival inflammation.

Valderhaug and Birkeland (1976) assessed fixed dental prostheses five years after cementation. They found when crown margins were located subgingivally, there was an increase in gingival index scores, in pocket depth, and in lost attachment compared to supragingival placement. They felt little damage is likely to be caused to the periodontal tissues when the crown margins are located supragingivally.

Palamo and Peden (1976) stated that when a dentist places a subgingival margin, he is choosing to place a groove or surface deficiency in the gingival sulcus that will enhance

plaque accumulation. They felt one should consider the esthetic result of gingival inflammation, with redness, bleeding, shiny appearance, and swelling resulting from subgingival margins in the evaluation of patients. .

Wilson and Maynard (1981) questioned whether any restoration margin which extends over 1 mm into a healthy gingival crevice, even if totally confined to this crevice, can adequately be cleansed by the patient. They recommend the use of the porcelain butt jacket in the case of the shallow crevice because the margin is not carried as deeply into the crevice as the metal-ceramic crown with a collar. They also stated the metal-ceramic crown may have two areas where plaque accumulates: at the margin and at the junction of the porcelain metal collar.

Lang et al. (1983) found that following the placement of restorations with clinically perfect margins, a microflora characteristic for gingival health or initial gingivitis was observed. Following the placement of restorations with overhanging margins, a subgingival flora was detected which closely resembles that of chronic periodontitis. Ericsson and Lindhe (1984) demonstrated that the placement of a restoration in a subgingival position in gingival sites allowed to accumulate plaque established conditions which promoted development of moderate to severe gingival inflammation.

Carranza (1984) recommended that dental restorations should be kept away from the gingiva whenever possible. Extension of cavity margins into the gingival sulcus should

occur only in those situations when there is a definite indication for introducing restorative materials into the subgingival environment. If the decision has been made to place the restoration subgingivally, it is advisable to keep it in the coronal half of the gingival crevice. This is echoed by Nevins and Skurow (1984) when they state the singularly most challenging aspect of the complete coverage restoration is the placement of the intracrevicular margin.

B.   Metal-Ceramic Margin Design

In spite of meticulous tooth preparation and management of the supporting gingival tissues, a frequent problem is the exposure of the metal collar either before or after cementation. The angulation and available light render it black in appearance and patients often find it objectionable. Another difficulty is that of high reflectivity and value at the gingival margin of the porcelain. To mask the color of the underlying metal, opaque porcelain must be used. Since this is carried close to the surface, the thickness of gingival porcelain that overlies the opaque is usually insufficient to allow adequate diffusion of light, resulting in a surface of high specular reflection (Donovan and Prince, 1985). Several metal-ceramic margin configurations have been used to resolve the esthetic problems. It has proven to be difficult, though, to devise a design that will provide excellent esthetics, promote periodontal health, and maintain good marginal closure.

A beveled shoulder finish line is considered by many to be the margin of choice (Hobo and Shillingburg, 1973). There

are two main advantages to the beveled shoulder configuration. The first advantage is that use of a bevel compensates for cementation errors and inherent defects in the casting process. This was first described by Rosner (1963) in relation to gold castings. Preston (1977) later applied this concept to metal-ceramic restorations. The second advantage of this margin configuration is that it has demonstrated less creep or distortion on firing the porcelain.

Mumford (1965) suggested several reasons for the distortion of veneered castings. Among them are contraction of the porcelain with subsequent metal deformation, contamination of the internal surface of the casting with porcelain, contamination of the casting, and grain growth of the alloy. He felt most problems arose from the first reason.

Silver et al. (1960) observed that if the marginal metal was thinned beyond 0.5 mm, the porcelain when applied would buckle or bend the metal in the thin portions resulting in a change of the fit. With regard to grain growth, he suggested that the cast alloy was infested by contaminating substances from the master cast and became enlarged during the firing process. This led to the orifice of the casting becoming smaller and hence to a shrinkage of the coping.

Shillingburg et al. (1973) published the results of marginal gap changes that resulted during each firing cycle for four different coping designs. Specimens of a Au-Pd-Ag alloy were fabricated for adaptation to dies with shoulder, shoulder-bevel, chamfer, and chamfer-bevel preparations. They

found that the shoulder finish lines afforded some protection against distortion during porcelain firing. The greatest marginal opening changes occurred during those stages when porcelain was fired to the copings. All four specimen designs exhibited progressively greater marginal gap changes from the first firing of body porcelain.

Faucher and Nicholls (1980) introduced a technique for monitoring marginal changes which occurred during a series of firing procedures. The external surface of the margin was traced and profiled in two dimensions. For each crown, there was an increase in the mesiodistal dimensions and a decrease in the faciolingual dimensions. Although most of the distortion occurred during the oxidation cycle, additional dimensional changes occurred during subsequent firing procedures. Specimens with a chamfer preparation exhibited significantly greater distortion than did the shoulder or shoulder-bevel designs.

Buchanan et al. (1981) reported greater marginal distortion of a base metal alloy compared to a Au-Pt-Pd alloy when fired with porcelain. The metal oxidation procedure resulted in a marginal opening change of about 70 microns for base metal and 7 microns for the gold base alloy. Subsequent simulated opaque and body porcelain firing procedures produced little additional gap changes compared with those as a result of the oxidation cycle. The larger distortion for the base metal alloy was attributed to the formation of a layer of oxide on the internal surface of these copings.

Hamaguchi et al. (1982) found no significant marginal distortion when porcelain was fired regardless of marginal design. They concluded that porcelain application and firing does not mechanically distort the facial margin because the layered porcelain "sandwich" - opaque, body, enamel, glaze - precludes metal creep.

DeHoff and Anusavice (1984) utilizing dilatometric data analyzed residual stress and marginal distortion due to thermal contraction mismatch between metal and ceramic. Calculated marginal distortions due to crown design and metal-porcelain thermal contraction imcompatibility were found to be well below experimental values in the literature. For the cases studied, the calculated marginal distortions due to metal-porcelain thermal contraction mismatch depend primarily on the metal-porcelain combination and are insensitive to coping design. This study excluded copings which have been extensively ground to thickness of 0.1 mm or less, and such copings may be more susceptible to localized or generalized distortion.

Well documented is the fact that castings fail to seat (Jones et al., 1971; and Eames et al., 1978). With a shoulder margin, the gingival opening equals the amount the crown fails to seat at the occlusal surface. With the use of a bevel, it can be described geometrically, that as the bevel approaches parallelism with the path of insertion of the restoration, the cement thickness is minimized between the tooth and the

internal surfaces of the castings at the margin (Kashani et al., 1981).

Pascoe (1978) found the least marginal discrepancy was produced with a shoulder of the slightly oversized casting rather than a bevel. Gavelis et al. (1981) demonstrated that the best seal comes from the feather edge and parallel bevel preparations consistent with geometric considerations. The best seating, however, during cementation was produced with a 90° full shoulder and the poorest seating was produced with the 90° shoulder with parallel bevel. This is explained on the basis that shoulder preparations have poor seal prior to cementation, facilitating cement escape marginally.

To clarify the controversy, McLean and Wilson (1980) presented mathematical evidence indicating that bevels must be in the region of 70°-80° to produce significant improvement in marginal seal and decrease cement dissolution. Geometrically, the steeper the bevel, the thicker will be the metal collar. Serious difficulties will be encountered if an attempt is made to hide this collar in the gingival crevice. The problem of preparing a margin close to the epithelial attachment is obvious, as are the difficulties of tissue retraction and impression making. Verification of marginal integrity is almost impossible at this level (Christensen, 1966). With the use of a steep bevel, difficulties are encountered during firing of the porcelain veneer and during seating. Flexure of the metal will result

in cracking or fracture of the porcelain leaving opaque or metal exposed (Stein and Kuwata, 1977).

If the metal is thinned significantly in an attempt to eliminate the metal collar, the margin will distort when porcelain is fired, which negates the advantage of improved fit (Donovan and Prince, 1985). Covering the bevel with porcelain is also doomed to failure, because it cannot be done without overcontouring the restoration. Since porcelain shrinks to the region of greatest bulk, the porcelain over the bevel will be porous which results in poor esthetics and plaque adhesion (Preston, 1977).

The sloped shoulder configuration is another popular margin for anterior teeth. It is difficult to prepare and it seems the relatively thin section of metal would make the margin susceptible to creep and distortion (Donovan and Prince, 1985). Magnification of the work is desirable (Weiss, 1981) as the casting is milled to a knife-edge at the exact margin without overextension. Porcelain is then fired to the same exact line. The luxury of slight overextension in the metal must be eliminated, otherwise reduction of the metal overextension in the final polish will produce a metal collar and opaque line.

To prevent exposure of the opaque line at the interface, Kuwata (1979) has advocated triangulation of the metal, opaque, and porcelain in the marginal and interface areas and to bond thin layers of the three different materials at the point of the triangle. Fear of exposing the buccal metal margin

while shaping the porcelain intimidates the dentist or technician and overcontouring can easily occur. Where indicated, the substitution for this design with the all-porcelain buccal margin reduces this problem.

C. Collarless Metal-Ceramic Techniques

The collarless metal-ceramic restoration has recently become increasingly popular. There are significant biologic and esthetic advantages to this hybrid restoration, which combines the esthetics of the porcelain jacket crown in the region of the labial cervical third of the tooth with the strength of the metal ceramic restoration. From an esthetic point of view, the results are excellent because the metal collar is eliminated and opaque need not be near the labial surface. Although it cannot be stated categorically that glazed porcelain is the best material from a biologic standpoint, several studies have suggested this (Wise and Dykema, 1975; Clayton and Green, 1970; Volchansky et al., 1974; and Kaqueler and Weiss, 1970). Laboratory techniques for the fabrication of the collarless metal-ceramic restoration have been classified as platinum foil, refractory die, and direct lift.

The use of a platinum foil matrix was a logical extension of a familiar technique employed in fabricating porcelain jacket crowns. It was described nearly 30 years ago, when the metal-ceramic crown was in its infancy (Brecker, 1956). Hagen, in 1960, described a hybrid of this technique as the

restoration was formed in two units: a metal lingual and a porcelain facial constructed on a platinum foil matrix.

Johnston et al. (1967) and Jeffrey (1969) swaged a small piece of platinum foil to cover the labial, mesial, and distal shoulders of the die. The crown's substructure was then fabricated in wax on the die incorporating the foil. This was then cast in gold so that the foil would be attached to the casting. The removal of the casting from the investment proved difficult because the foil was easily damaged.

To incorporate the advantages of firing porcelain against a platinum matrix and to avoid the technical difficulty of preserving the matrix during investing, casting, and metal contouring and finishing procedures, Goodacre et al. (1977) spotwelded the platinum foil to the crown after it had been cast. Lacy (1982) used a combustible resin on the foil with the above technique before the addition of the first body bake material to eliminate foil distortion during firing.

Choung et al. (1982) presented a technique utilizing gold powder to fuse the platinum foil to the casting in place of spotwelding. This allowed for the removal of excess foil from inside the casting, permitting the casting with its attached matrix to fit the die accurately.

The use of the platinum foil technique requires an exceptionally critical tooth preparation because a smooth labial shoulder must be prepared to facilitate adaptation of the foil. Another significant disadvantage of the foil technique is the lack of direct visualization of the margin

during contouring. Though this technique has been used for many years with excellent results and is considered the standard to which other methods are compared, the proliferation of alternative techniques is ample evidence that it is both technically demanding and time consuming (Prince and Donovan, 1983).

As an improvement over the platinum foil concept, the use of a refractory die was introduced (Vickery et al., 1969; Southan and Jorgensen, 1972). By avoiding intermediary materials and baking the margin directly on a refractory die, it was felt that improved marginal integrity would result. An alternative technique using a metal-ceramic coating agent on the shoulder causes the porcelain to shrink towards the margin, which might improve the fit even more (Sozio and Riley, 1977; Sozio, 1977).

Though satisfactory results can be achieved, both techniques can be exceedingly demanding (Schneider et al., 1976). The lack of color differentiation between the refractory die material and the body porcelain can be difficult when shaping the margin. The additional step of die duplication, the friability of the refractory materials, and the sticking of the porcelain to the die material have made these techniques less attractive.

To circumvent the shortcomings of the previous two techniques and to simplify the fabrication procedure, the direct lift-off method has been employed. The main advantage of the direct lift technique is its relative simplicity. There

is no need to meticulously adapt platinum foil or to make a refractory die, which may be fragile.

Toogood and Archibald (1978) demonstrated a technique in which the porcelain shoulder could be established on the master die. The metal-ceramic restoration is fabricated in the conventional manner. The labial margin is formed after the crown has been developed to full contour. The margin is formed and corrected by adding body porcelain powder and water to the labial margin and placing the crown back onto the die. When thoroughly condensed the crown is removed again from the die and fired. If a marginal discrepancy occurs, more porcelain is added at the marginal openings and fired again. This is repeated until acceptable marginal adaptation occurs. Vryonis (1979, 1982) introduced the concept of forming the margin first with opaque porcelain and then completing the crown buildup. A final corrective bake using three parts body porcelain to one part correctional powder followed.

Instead of opaque porcelain to form the initial margin, McLean (1980a) used a combination of one-third aluminous core porcelain to two-thirds conventional opaque porcelain. This is reported to result in a margin with decreased pyroplastic flow and a reduced tendency to round off during glazing.

As first proposed, the direct lift technique has several problems. The porcelain has a tendency to stick to the die making the lift off difficult. Porcelain may seep under the casting to prevent the crown from fully seating. Adaptation of porcelain into small discrepancies at the margin is also

difficult (Prince and Donovan, 1983). Prince et al. (1983) suggested using wax instead of distilled water or modeling liquid as the vehicle in mixing the porcelain. This porcelain/wax mix is heated and flowed into the marginal discrepancies. In a comparison of different collarless crown techniques, Prince and Donovan (1983) recommended the porcelain/wax technique because of its ease in construction, handling characteristics, and the fact that it can undergo unlimited modifications.

Pinnell et al. (1986) have introduced a technique in which a light cured bonding resin is used to transport the porcelain powder rather than water or wax. The combination of bonding resin and porcelain creates a mixture that is easily applied and readily contoured to the desired shape.

D.   Porcelain/Wax Material and Porcelain Strength

The technique of substituting organic liquids, such as alcohols for the water vehicle, have been previously reported (Daskalon et al., 1975). Prince et al. (1983) were the first to utilize wax as the porcelain binder. This technique has also been suggested for use on the tissue surface of fixed denture pontics (Donovan et al., 1985).

Riley et al. (1985) reported on the development and use of an organic liquid binder which, when mixed with porcelain powder, immediately permits visualization of the true color. They stated by forming a gel-like paste with the porcelain powder, the organic mix prevents hydraulic classification of the powder particles during condensation, a process which

can be a problem with existing aqueous binders. They point out that any organic liquid used as a binder must be nontoxic, have no objectionable odor, and leave no residue. Any such impurities may react at firing temperatures and alter the properties of the base glass.

The outer surface of porcelain contains not only depressions from air bubbles or voids which reached the surface or became exposed during grinding or polishing, but also microcracks which may measure less than 0.2 microns wide (McLean, 1979). These microcracks are formed because the outside of the porcelain cools faster than the inside and forms a "skin" surrounding the still molten center. This "skin" may partially prevent the center from undergoing complete thermal contraction upon cooling which initiates tensional stresses within the porcelain that distort or rupture the outer skin producing the microcracks (Phillips, 1973). Griffith (1920) and Duckworth (1951) theorized that microcracks can act as stress concentrators, and when their critical stress is exceeded, the microcracks propogate through the porcelain causing it to fracture.

Compressive forces restrict the propagation of the microcracks; tensional forces can cause their propagation (McLean, 1979). Dental porcelain has a compression strength of 50,000 p.s.i. and a tensile strength of only 5,000 p.s.i. (McLean and Hughes, 1965). Tensile forces are those which are responsible for the fracturing of dental porcelain (Southan

and Jorgensen, 1973) and are of particular concern when examining porcelain labial margins.

McLean and Sced (1976) stated that the torsional stresses placed in the incisal third can initiate tensile stresses within crowns, especially in the cervical third. Prince et al. (1983) stress the importance of not placing a shoulder greater than 90° in the collarless metal-ceramic crown preparation to reduce the forces of tension. Porcelain butt joint strength has been measured at approximately 5,000 p.s.i., which is approximately equal to its tensile strength (O'Brien and Ryge, 1978). The National Bureau of Standards supports these findings and states that the tensile test demonstrates the best correlation to the strength of margins (Schoenmaker, 1972).

In order to evaluate the clinical acceptability of the porcelain/wax technique, it is important to evaluate the quality of the resulting porcelain. Schrader et al. (1984) measured the volumetric shrinkage of the resulting porcelain when wax was used as the vehicle and compared this shrinkage to that of porcelain which utilized the conventional water and porcelain mix. The porcelain and wax resulted in significantly less shrinkage than the conventional water and porcelain mix.

Gordner (1985) recently confirmed this finding; however, he demonstrated the decrease in porcelain shrinkage attained was due to an increase in porosity. As the ratio of porcelain to wax increased, the shrinkage percentage, apparent specific gravity, and transverse rupture strength decreased. He

recommended the use of a porcelain/wax technique only in limited situations and then with a ratio of 6:1 by weight.

E.   Collarless Metal-Ceramic Restoration - Marginal Fit

The limit of clinical acceptability regarding marginal fit is subject to controversy in the dental literature. The cement film thickness serves as a guideline as to the maximal amount of marginal opening of a well-adapted margin. The American Dental Association's standards for the maximum film thickness of dental cements is 25 microns (American Dental Association, 1976-78). This is in agreement with the research of Christensen (1966) and Jorgenson and Wakumoto (1968), which demonstrated that a 39 micron marginal discrepancy was clinically acceptable.

The fit of a restoration in vivo is assessed either by means of a sharp explorer or by radiography. The term "good clinical fit" may have several interpretations in restorative dentistry depending on the sharpness of the explorer tip and the skill of the clinician. Clinical detection of the marginal discrepancies in porcelain crowns is a difficult task. Bjorn et al. (1970) have shown that some clinicians accept defects larger than 200 microns. McLean and Von Fraunhofer (1972) in a survey of 1,000 porcelain crowns over a five-year period concluded that a marginal gap of less than 120 microns could be considered successful. A recent study (Dedman, 1982) reported that the mean size of discrepancy accepted was 93 microns for overhangs and 114 microns for openings when dentists evaluated margins with their eyes closed.

Porcelain inlays were found to have mean marginal openings of 36 microns (Christensen et al., 1969). Schneider et al. (1976) found similar results when the porcelain shoulders of collarless crowns were shown to have a mean marginal opening of 38.8 microns. In his study of the marginal fit of collarless metal-ceramic crowns, Ullman (1972) found mean marginal openings of 93.9, 35.1, 17.69, and 17.55 microns.

When porcelain shoulder margins were compared to gold margins fabricated from the same standardized crown die, the porcelain shoulder margins were found to have a marginal opening of only 6 microns compared to the gold margins which had openings of 17-34 microns (Vryonis, 1979). Belser et al. (1985) examined the comparative fit in vivo of three types of metal-ceramic crown margins. There was no significant difference among beveled metal margins, metal butt margins, or porcelain butt margins before or after cementation. They demonstrated it was possible under clinical conditions to consistently produce porcelain margins with less than 50 micron marginal openings.

Cooney et al. (1985) evaluated various techniques for forming ceramic margins on metal-ceramic restorations. Ceramic margins formed with a platinum foil technique (32-38 microns) showed significantly better fit than a wax binder technique (81 micron mean) and a shoulder porcelain (direct-lift) method (70 microns).

Hunt et al. (1978) demonstrated that the traditional approach of using a traveling microscope or the more accurate

method of cross-sectional measurement using high power optical microscopy was not wholly valid for the porcelain margin. Rather than attempting to detail a particular marginal gap, the marginal characteristics were defined by measurements at two sites. The porcelain at the extreme edge was rounded due to shrinkage during firing, producing a larger marginal discrepancy at the extreme labial edge.

West et al. (1985) measured the gap between the porcelain and the die shoulder at three standardized locations. The marginal site X was on the shoulder where the first effects of marginal rounding could be detected. Site Y was 0.4 mm along the die shoulder below site X, and site Z was at a point on the die shoulder below the metal-porcelain interface. They found crowns constructed with platinum foil matrixes had sharper cavosurface margins than those constructed by two direct lift-off techniques. The direct lift-off techniques showed more cervical porosity than crowns made with platinum foil. The use of specially formulated shoulder porcelains for the direct lift-off technique, however, was not employed.

According to McLean (1980) the pyroplastic flow of body porcelain is greater than that of opaque porcelain at the glazing temperature. Therefore, to assure adequate marginal adaptation of the labial margin, the margin should be placed in the opaque porcelain with low pyroplastic flow characteristics. McLean (1980) and Hubbard (1977) recommend that the technician formulate a special alumina/opaque mixture consisting of one part by weight of aluminous Vitadur Core

Porcelain mixed with two parts by weight of Vita VMK 68 Opaque Porcelain. The resultant mixture is used to fabricate the labial cervical margin only. The high alumina content of the Vitadur core material acts to both strengthen the marginal porcelain and decrease pyroplastic flow during subsequent firings. The recent development of VMK Shoulder Porcelains by Vita Zahnfabrik have simplified the technique.

Brukl and Philp (1985) took the technique of Hunt et al. (1978) a step further in their evaluation of Cerestore, twin foil, and conventional ceramic crowns. The fit of the crowns to standardized dies was evaluated by measuring the total area of the cement space between the crown or foil and the die with a digital planimeter on enlarged photographs. The exact magnification of each enlarged photograph was calculated from the measured die shank of each embedded sample. With the exact magnification of each photograph, the actual sample cement space areas were determined. This technique of marginal evaluation has yet to be applied to the collarless metal-ceramic restoration.

F.   Metal Design for Collarless Restorations

Metal substructure design for the collarless metal-ceramic restoration utilizing a direct lift fabrication technique consists of three distinct configurations. These are: feathering it "0.3-0.5" mm short of the external margin; bringing the metal to the axiogingival line angle; and leaving it 0.5 mm short of the shoulder.

Feathering the metal substructure short of the external margin (Toogood and Archibald, 1978; Hunt and Cruickshanks-Boyd, 1980; Scharer, 1983; Unitek Technique Manual, 1985) allows the shrinkage of the porcelain shoulder during baking to be reduced to a minimum; however, it may introduce a problem with metal distortion and esthetics. The problem with metal distortion can be remedied as errors are minimized because the shoulder porcelain is adapted directly to the die and repeated addition of porcelain can substantially improve the gingival margin. It is felt this design provides more strength to the margin area than the other designs. The esthetic results of this design have not been investigated.

By far the most popular method is bringing the metal to the junction of the axial wall and shoulder floor (Vryonis, 1979; La Hoste, 1981; Prince et al., 1983; Zalkind, 1984; and Howard, 1985). This is a direct modification of the platinum foil and refractory die techniques and is recommended since it results in improved color due to the increased porcelain thickness at the gingival margin.

The concept of leaving the metal short of the shoulder (Behrend, 1982; Vryonis, 1982; Vita Zahnfabrik, 1985; and Chiche et al., 1986) was developed to avoid the darkening effect of metal on adjacent tooth structure. Unitek's Porcelain Technique Manual (1985) recommends avoiding this design, but does not expand upon a reason. A possible explanation might be the increased number of correctional bakes used to fabricate

this margin, resulting in the stepping of the porcelain. This question has not yet been addressed in the literature.

Presently there have been no investigations on how porcelain adaptation to the shoulder is affected by metal substructure design. A recent investigation by Cooney et al. (1985) found the platinum foil method for forming ceramic facial margins provided a better marginal adaptation than a direct lift technique utilizing a wax binder. They stated with the platinum foil technique, the porcelain adheres to the foil as it fuses rather than shrinking toward the main body of porcelain as occurs with the direct lift technique. The question of whether modification of coping design would improve the results of the direct lift technique was addressed but not expounded upon.

The purpose of this investigation is to examine the effect of metal coping design and fabrication technique on the marginal characteristics of the collarless metal-ceramic restoration.

III. METHODS AND MATERIALS

Laboratory protocol must ensure replicate samples and reproducible measurements for valid material evaluation. The benefit of the use of the stereo microscope as an adjunct to laboratory technology has been addressed in the dental literature (Oliva et al., 1982; Wohlwend, 1984; Rinn, 1985; Chou and Pameijer, 1985; and Titus, 1986). To ensure the performance of technical procedures with the utmost precision, a stereo microscope (Swift M81B, Seiler Instrument & Manufacturing Co., Inc., St. Louis, MO) was an integral part of the laboratory armamentarium.

A.   Fabrication of Standardized Gold Copings

A master die having a 2.5-degree axial wall taper, a 1.5 mm gingival shoulder, a crown height of 7 mm, and an occlusal diameter of 6.1 mm was machined in plexiglass (Plate 1). The occlusal-axial and the axial-gingival line angles of the die were rounded to reduce internal stresses in the restorations and a small notch was placed at the occlusal-axial line angle to prevent rotation of the restoration during fabrication. The master die was a modification of one previously described by Philp and Brukl (1984) for use in a specially designed sculpturing device which was employed to achieve an equal and uniform crown wall thickness.

Twenty impressions were made of the master die with an addition reaction silicon material (President; Coltene, Inc.,

Plate 1. Plexiglass Master Die

Hudson, MA). Each impression was poured in a refractory die investment stone, DVP (Whip-Mix Corp., Louisville, KY), following the manufacturers' instructions for minimal expansion. Three working dies were made from each impression providing a total of sixty.

To ensure uniform wax application for each specimen, the sculpturing device previously described was now employed. A 0.4 mm feeler gauge was utilized to establish the distance between each die and a movable template which was attached to a ball bearing race (Plate 2). The angle of the axial wall of the die and template remained constant at 2.5 degrees. A hard inlay wax (Maves Co., Cleveland, OH) was then applied in slight excess of 0.4 mm and the template was revolved symmetrically around the die sculpturing the wax to a uniform 0.4 mm thickness (Plate 3). To aid in the casting of the specimens and to provide a control, a lingual wall of wax was added. A silicon putty matrix allowed for standardization of the bulk wax buildup (Plate 4) and a second movable template at 1.5 mm from the die allowed for uniform sculpturing (Plate 5). Each of the 60 specimens were fabricated in this manner.

The majority of each refractory base was then removed and the wax coping die systems were secured by 8 gauge round wax sprues on a rubber sprue former in groups of three. A 5 mm piece of 18 gauge round wax was placed on each lingual surface to provide handles to aid in the fabrication of the restorations (Plate 6). Each group of three was then invested in a phosphate-bonded material (Ceramigold; Whip-Mix Corp.,

Plate 2. Feeler Gauge Establishing Distance
         Between Die and Rotating Template
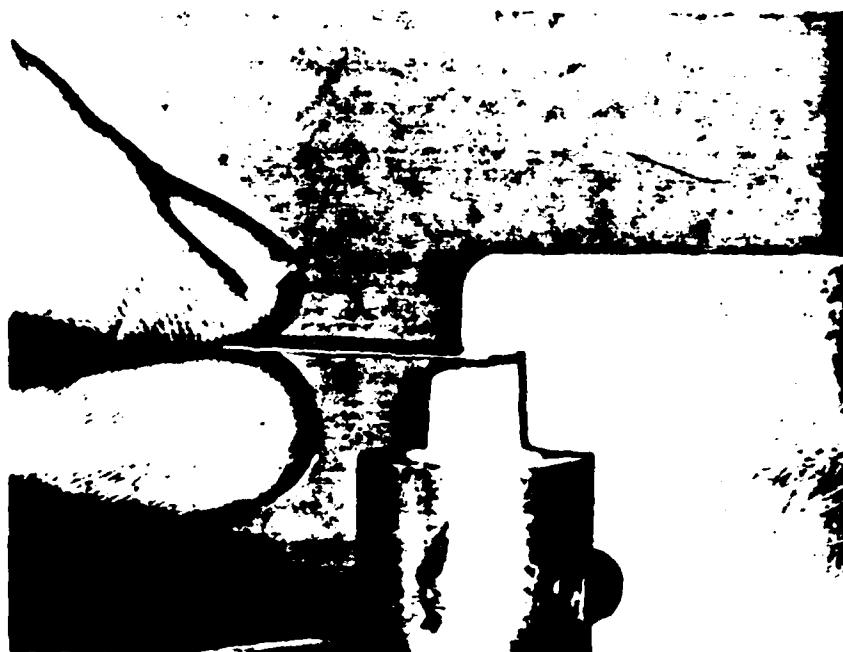
Plate 3.   Sculptured Wax Coping
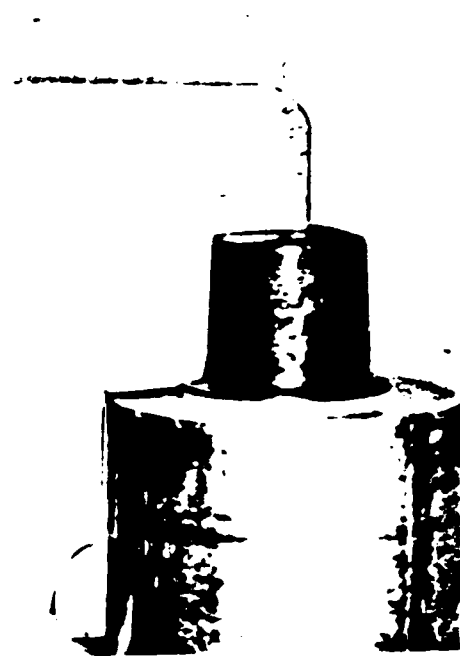
Plate 4. Silicon Putty Matrix for Lingual Wall
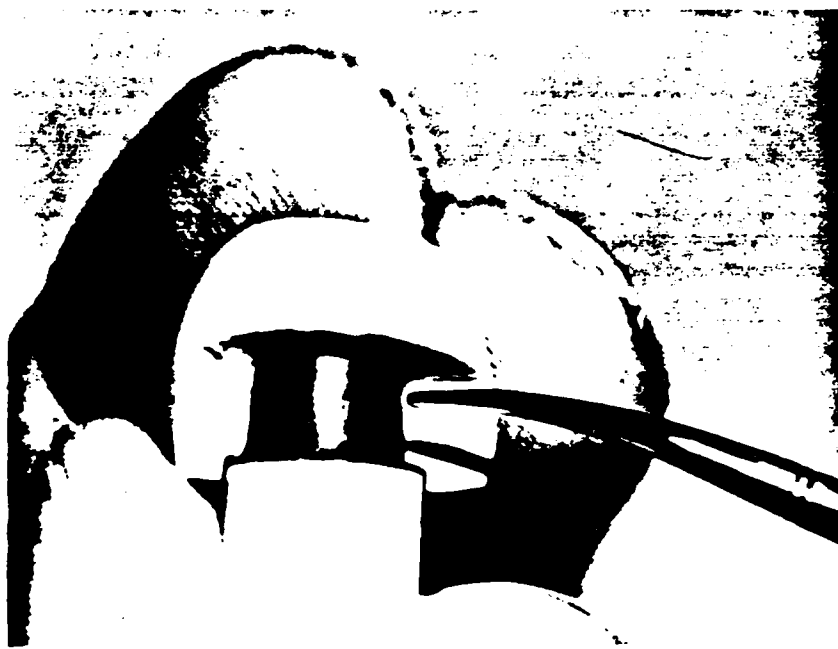
Plate 5.   Second Template Sculpturing Lingual Surface
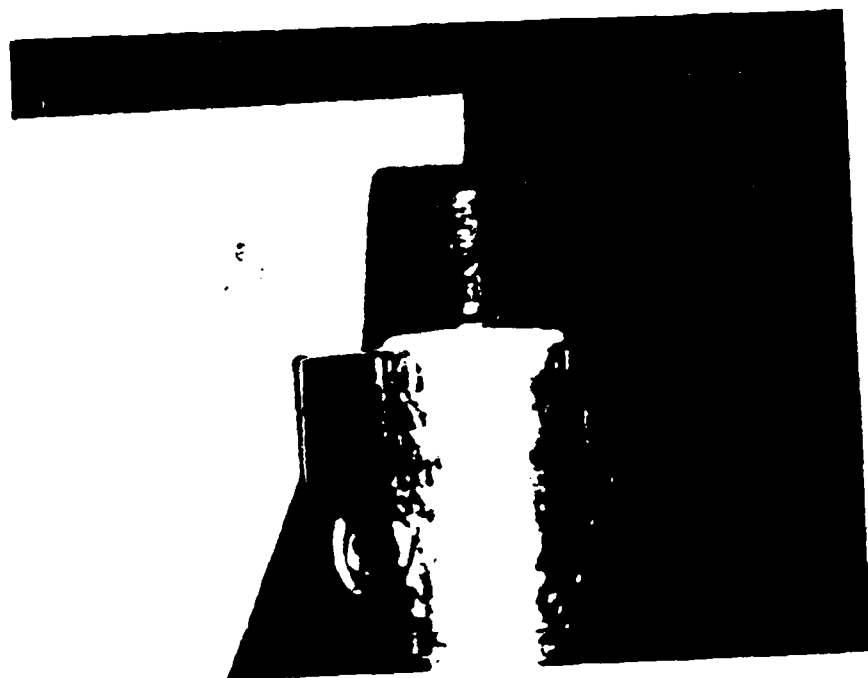
Plate 6. Sprued Wax Copings
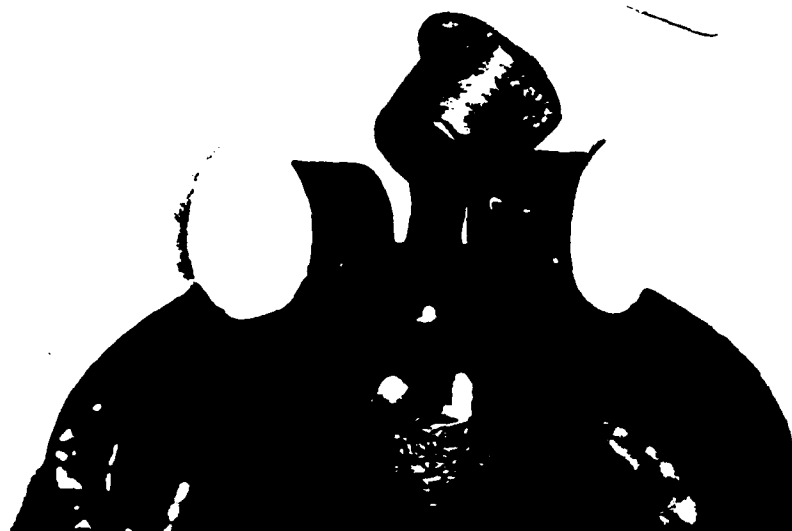
Louisville, KY) using the manufacturer's recommendations for its use with DVP investment. Gold castings were then made in Olympia metal (J. F. Jelenko and Co., New Rochelle, NY) using a centrifugal casting machine and following the recommended procedures for the alloy.

The metal copings were divested and cleaned manually, separated from their sprues, and inspected for nodules which were either "flicked" off with a sharp instrument or removed with a 1/2 round carbide bur. The shoulder area of each casting was carefully finished to a smooth flat surface by successive abrasion on 240 through 600 grit silicon carbide strips (Buehler Ltd., Lake Bluff, IL) with water as a lubricant. A small notch was then placed on the internal aspect of the shoulder at the midpoint of each casting buccal-lingually to provide an alignment guide during custom die fabrication. The castings were then sandblasted on the inner fitting surface for three seconds and for six seconds on the outer surface at 40 psi using 25 micron particle size aluminous oxide abrasive. Marginal exposure to the sandblasting was limited by the use of a fine jet nozzle at close range on the fitting surface and pressing the margins in the rubber glove when the outer surface was air-abraded. The copings were then steam cleaned for 15 seconds and blown dry with compressed air to ready them for the oxidizing cycle. With a recently calibrated Ultra-mat porcelain furnace (Unitek Corp., Monrovia, CA), the copings were preheated, air fired to 1035°C at a climb of 55°C/minute, and then allowed to cool slowly.

B. Fabrication of Custom Dies

To fabricate working dies, a method similar to that described by McCune (1968) and Gavelis, et al. (1981) was employed. Duralay resin (Reliance Dental Manufacturing Co., Worth, IL) was overbuilt in each casting by a technique described by Thomas and Baylis (1986). A brass dowel pin was then inserted vertically into this overbuilt resin with slight hand oscillation. The resin was allowed to set a minimum of one hour, the excessive resin was then trimmed away from the margins with a sharp scalpel blade, and the resin was pulled out of the casting (Plate 7). The resin die was then carefully inspected to ensure no air pockets were entrapped during fabrication. To allow for the use of the sculpturing device during porcelain application, bases were now fabricated for each individual die by inserting the resin die into one of the initial silicon impressions of the master die and pouring a stone (Die-Keen; Whip-Mix Corp., Louisville, KY) base (Plate 8).

The casting-die systems were then randomly divided into two groups of thirty and the metal at the margin area was altered to conform to the two types of metal configurations under investigation. The first design allowed for metal to remain at the junction of the axial wall and shoulder floor and the second design left the metal 0.5 mm short of the shoulder (Plate 9). A 0.5 mm feeler gauge was employed to ensure a standardized cutback. Each group of 30 was then randomly divided providing 4 groups of 15. To prepare the

Plate 7.   Trimmed Resin Die and Cast Coping

Plate 8. Resin Die in Original Impression to
Allow Stone Base to be Fabricated

42
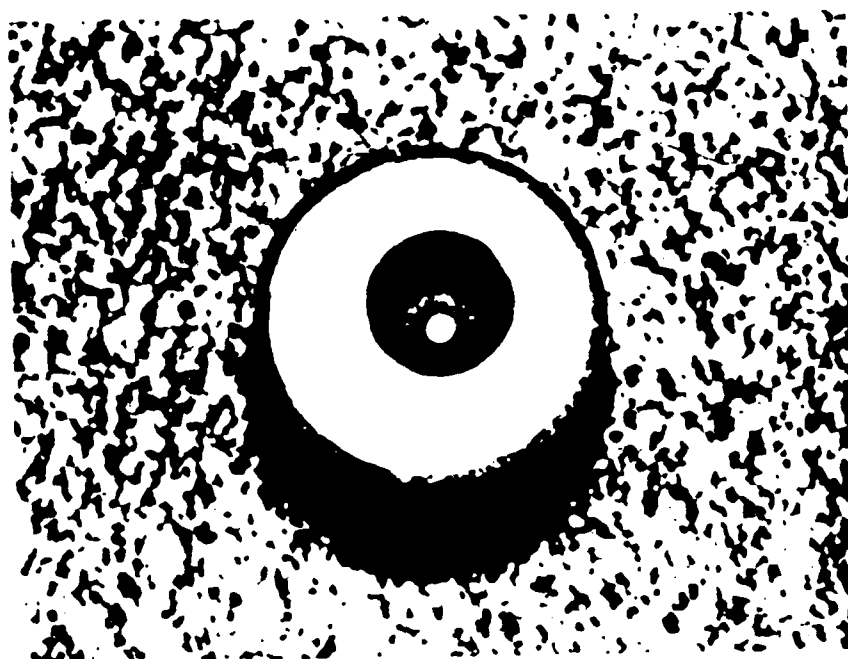
Plate 9.   Shoulder Metal Designs: Left, Metal to Shoulder;
           Right, Metal 0.5 mm Short of Shoulder
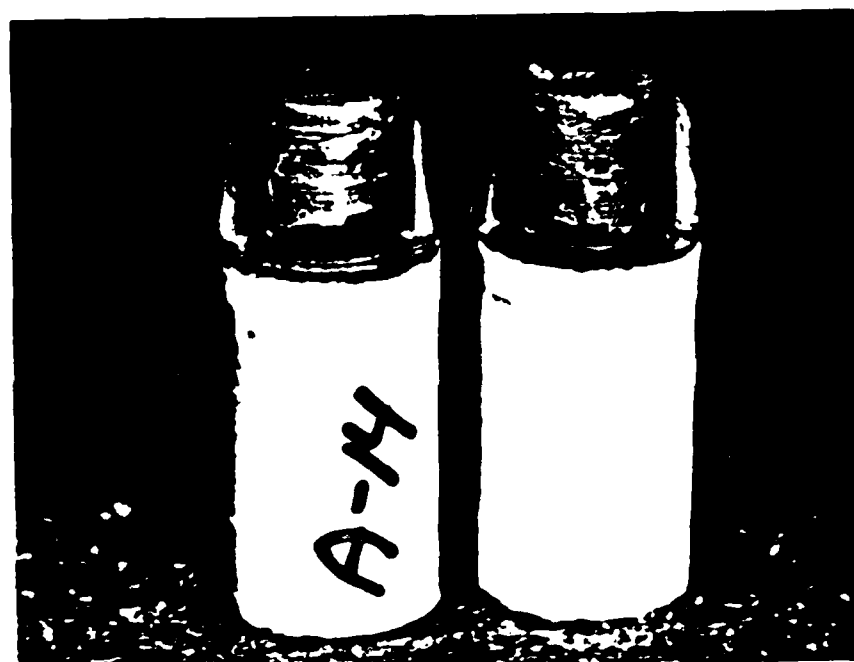
castings for porcelain application each was again air-abraded, steam cleaned, and blown dry with compressed air.

C.   Porcelain Fabrication

To make the results of this investigation as clinically relevant as possible, the porcelain fabrication was conducted in a manner closely approximating the porcelain's actual clinical use and laboratory fabrication.

1.   Direct Lift Margin Technique

Two layers of shade 520 VMK-68 opaque (Vident, Baldwin Park, CA) were applied and fired (980°C, 970°C) as described in the Vita Technique Manual. If the opaque porcelain possessed a highly glazed surface, it was air-abraded lightly with aluminum oxide and then steam cleaned for 15 seconds. A lubricating film (Modisol; Vident) was applied to the shoulder area of the resin die to facilitate removal of the wet porcelain. The porcelain used to fabricate the shoulder area was a commercially available (594X; Vident) high-fusing, low shrinkage material designed for this purpose. VMK-68 modeling liquid (Vident) was used as the liquid medium.

Each coping was completely seated on its lubricated die and the shoulder porcelain was added. The initial increment of porcelain was placed only on the labial shoulder and extended 2 to 3 mm onto the metal coping. With the coping held firmly in place, the porcelain was condensed with vibration and dried with a tissue two or three times until very little moisture came to the surface upon vibration. The shoulder porcelain was slightly undercontoured except for that material that

was directly on the shoulder which would then allow for a layer of body porcelain to be placed over the shoulder material, creating a more vital appearance in the gingival area of the completed crown. The coping was then carefully lifted off the die and placed on a standard firing tray and allowed to thoroughly dry before firing under vacuum at 950°C.

When the coping was placed back on the die, a marginal opening of approximately 0.5 mm remained. To correct the margin, the shoulder of the die was again lubricated and a small amount of porcelain was placed on the gingival aspect of the previously fired shoulder. The crown was then placed on the lubricated die and carefully vibrated until it was completely seated. If the coping did not go to place on the die, it was an indication that porcelain seeped inside the casting. The restoration was then lifted off the die, the walls of the casting cleaned, and an attempt was made to seat the crown again. When the crown was completely seated, the porcelain was condensed and smoothed as before. If there were any open or undercontoured margins, a small amount of porcelain was placed from the labial. When the condensation was complete, the restoration was carefully lifted off the die and it was fired at the same temperature as the initial margin buildup. One additional correction firing was completed on each sample prior to the application of the standard body porcelain.

Although not critical for this investigation, the specially designed sculpturing device was utilized to achieve

and ensure uniform thicknesses of the porcelain walls. A feeler gauge ensured a 1.5 mm distance between the die and the second template. Body porcelain, shade D2 (Vident), was condensed and then sculptured with the revolving template on each coping (Plate 10). To standardize the fabrication, two body bakes were completed on each restoration. The first body bake was fired under vacuum at a rate of 55°C/minute until a final temperature of 920°C was attained. The firing for the second body bake was at 910°C.

A final marginal correction with shoulder porcelain was now accomplished at 910°C. The marginal area was then contoured and polished (Shofu porcelain adjustment kit; Shofu Dental Corp., Menlo Park, CA). A final glaze was placed on the restorations by firing at 920°C for one minute without vacuum.

2. Porcelain/Wax Margin Technique

The opaque porcelain application for these specimens was exactly the same as that previously described for the direct lift technique. A pilot investigation revealed that the initial marginal buildup could not be fabricated with a porcelain/wax mixture due to the excessive slumping which occurred when the mixture was allowed to volatilize beneath the muffle of the porcelain oven. To establish the initial margin buildup, the same technique as that employed for the direct lift specimens was utilized. All additional correction firings were completed with a porcelain/wax mixture.

Plate 10.   Rotating Template Sculpturing Porcelain
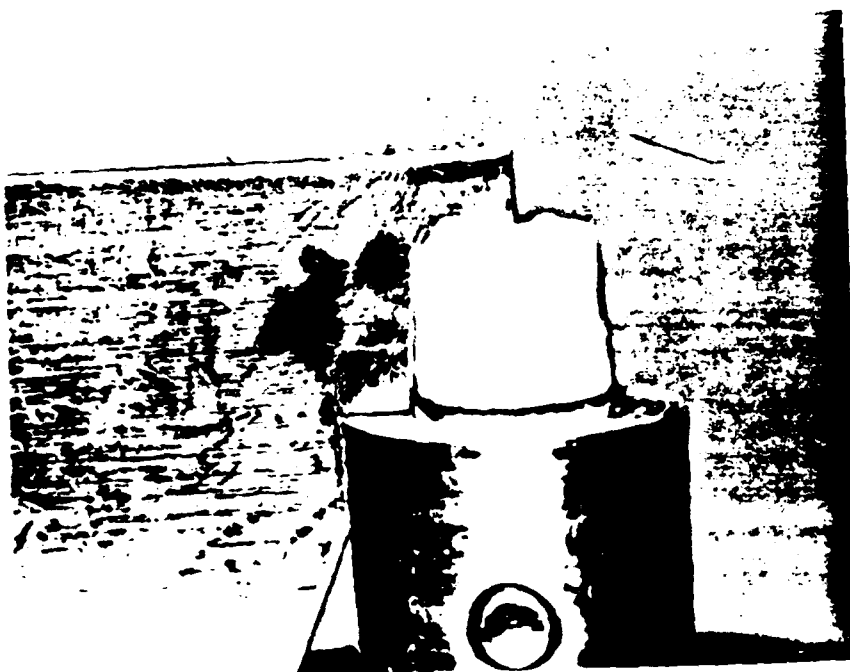
The fabrication of the porcelain/wax mixture was similar to that described by Prince, et al. (1983). Vita shoulder porcelain (Shade 594X, Vident) was mixed with wax (Plastodent U, Degussa, Long Island, NY) in a 6:1 porcelain to wax ratio by weight. Plastodent U is a totally synthetic blockout wax which avoids the inconsistent properties present in natural waxes (O'Brien and Ryge, 1978). The mixture was obtained by first melting the wax in a dappen dish placed in an electric wax unit (Wax Rite, Coe Laboratories Inc., Woodside, NY) prior to incorporating the appropriate amount of porcelain.

A light layer of porcelain separator (Modisol, Vident) was applied to the shoulder of the die. The porcelain wax mixture was applied to the marginal area with an electric wax spatula (Almore International Inc., Portland, OR). Once the shoulder was overpacked, it was condensed with pressure from the electric spatula. The wax spatula was then placed on the lingual metal area for 30 seconds to further condense by "drawing" the porcelain/wax mixture to the heat source. After the porcelain/wax material had sufficiently cooled, it was trimmed back to the margin using a warm wax carver. The coping was then carefully separated from the die to ensure the margin was complete and well adapted. The coping was then placed on a firing tray and very slowly introduced toward the firing chamber of the porcelain oven. The preheating of the coping in front of the muffle prior to firing was extended to ten minutes to assure complete volatilization

of the wax. The firing procedure was then the same as the direct lift technique. A second correctional bake with the porcelain/wax paste was performed and fired in a similar fashion.

The body porcelain application was applied in exactly the same fashion as that described for the direct lift technique. A final correction bake was then accomplished with the porcelain/wax paste prior to marginal contouring, polishing, and final glazing of the restoration.

D. Specimen Preparation

The finished restorations were seated on their dies and weighted on their occlusal surface with a static two pound load. A thin layer of alpha cyanoacrylate cement (Vigor Company, New York, NY) was painted on the external margin area of the restoration and die and allowed to dry. The stone base and a portion of the brass dowel were then removed from the resin die. Four small retention holes were made in the base of the resin with a #4 round carbide bur. The restorations were then individually embedded in a pourable polyester resin (Chemco Resin Crafts, Dubin, CA) which was allowed to cure for a minimum of 24 hours (Plate 11).

The embedded specimens were then sectioned occlusal-gingivally at the midpoint facial-lingually with a diamond saw (Isomet Low Speed Saw, Buehler Ltd., Lake Bluff, IL). An ultra thin diamond disk was used and the load, RPM, and direction of rotation was standardized. The sectioned crowns were then metallographically polished by successive

Plate 11. Restoration Ready for Embedding
in Polyester Resin
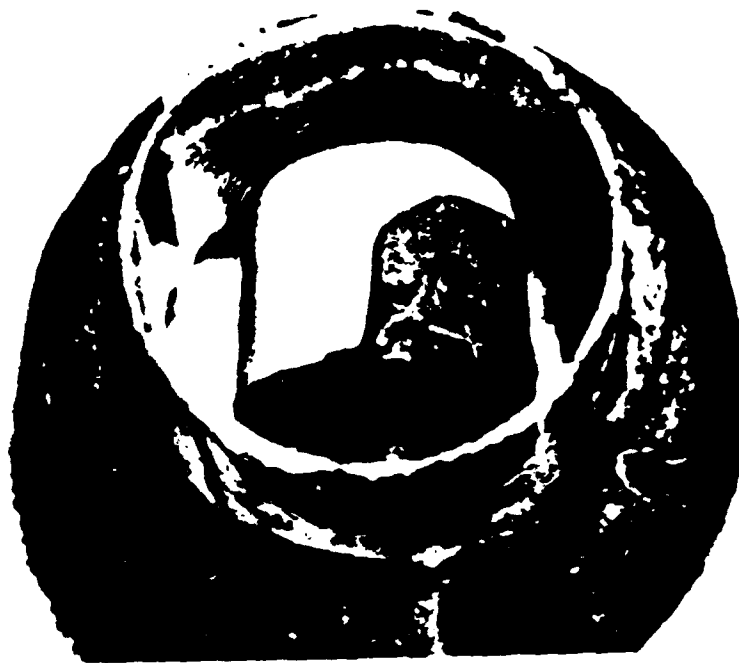
abrasion on 240 through 600 grit silicon carbide strips (Buehler Ltd.) with water as a lubricant. Final polishing was done on a rotary wheel with a six micrometer diamond paste, a Buehler nylon cloth, and Buehler oil extender lubricant. The purpose of the polishing operation was to remove any saw smearing to yield a macrostructure with sharply defined interfaces.

E. Measurements and Analysis

The facial and lingual margin openings were measured on each (right section) of the 60 specimens with a traveling microscope (Gaertner Scientific Corp., Chicago, IL). The measurements were made following a protocol described by Faull, et al. (1985) which allowed for overextended or deficient margins. Each marginal opening was measured three times and averaged to yield a mean marginal opening. The margins produced, as a result of the direct lift technique, were consistently sharp and easily read (Plate 12); however, those fabricated with the porcelain/wax mixture were difficult to read due to the rounding which occurred (Plate 13). To obtain a standard way of obtaining a measurement for these margins ten specimens were examined, and it was found that the rounding of the external margin was limited to the external 100 microns of the porcelain. A composite marginal opening for the porcelain/wax margins was produced by making three measurements, at the external margin, at 50 microns internal and at 100 microns internal. These measurements were then averaged to produce a mean marginal opening.

Plate 12.   Representative Margins from Porcelain/Liquid
            Technique

            A.   Specimen with Metal to Shoulder

            B.   Specimen with Metal off Shoulder
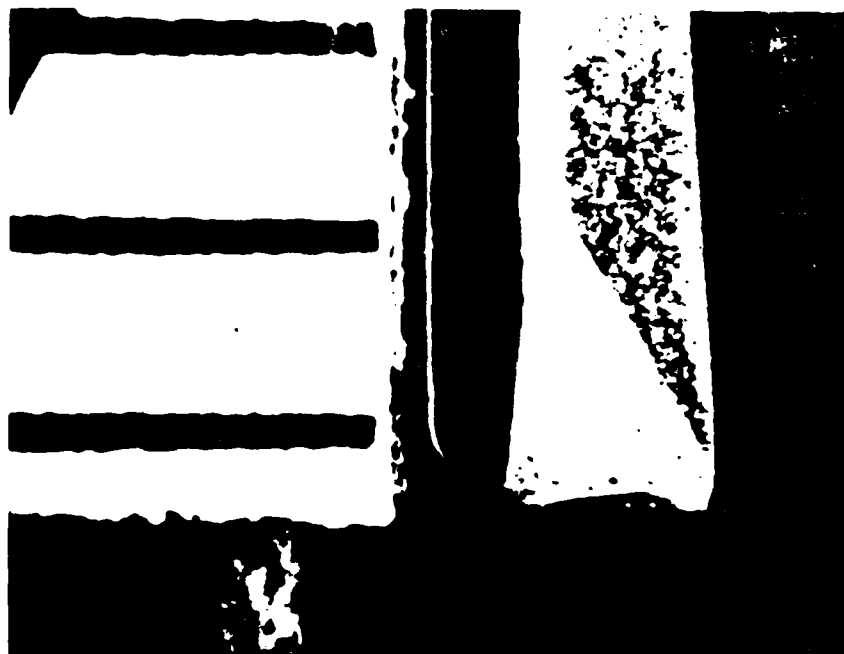
Plate 13.   Representative Margins from Porcelain/Wax
            Technique

            A.   Specimen with Metal to Shoulder

            B.   Specimen with Metal off Shoulder

To measure how well the porcelain was adapted to the shoulder, the conventional experimental technique of direct linear measurement was abandoned due to the jagged and irregular nature of the porcelain. The technique utilized was a modification of one previously described by Brukl and Philp (1985). Thirty-five mm photonegatives of each of the sixty sectioned and polished samples were made. A 4 mm rule was included in each photonegative to ensure a standard magnification and aid with measurements. Each photonegative was projected on an eight by eleven piece of paper at a constant magnification, and the space between the porcelain and the die was traced over an area 0.75 mm from the external margin. This measurement was established with the millimeter rule and set on a pair of dividers to ensure replication between tracings. This area was then divided into three equal sections of 250 microns each (Figure 1). The area of each section was then calculated with the aid of a Zeiss Interactive Digital Analysis Sytem (Carl Zeiss Inc., Thornwood, NY) (Plate 14). Four enlarged 250 micron squares fabricated from the measurement maintained with the dividers were each measured three times with the ZIDAS to establish a baseline measurement (a ZIDAS reading of 853.6 over 250 microns would yield a mean marginal opening of 100 microns). This baseline was then used to calculate a mean marginal opening of the outer 250 microns, from 250 to 750 microns, and the overall marginal opening over the initial 750 microns.

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Figure 1.   Tracings Representing Area Between Porcelain
and Shoulder of Die. A, B, C, and D correspond
to Plates 12A, 12B, 13A, and 13B, respectively.
Small section represents external margin to
0.25 mm internal. Large section represents
area 0.25 mm to 0.75 mm along shoulder.

A

B

C

D

55
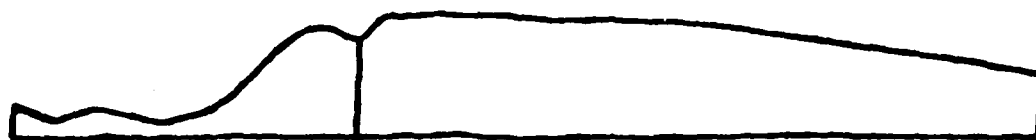
Plate 14. Stylus for Tracing with ZIDAS
(Zeiss Interactive Digital
Analysis System)
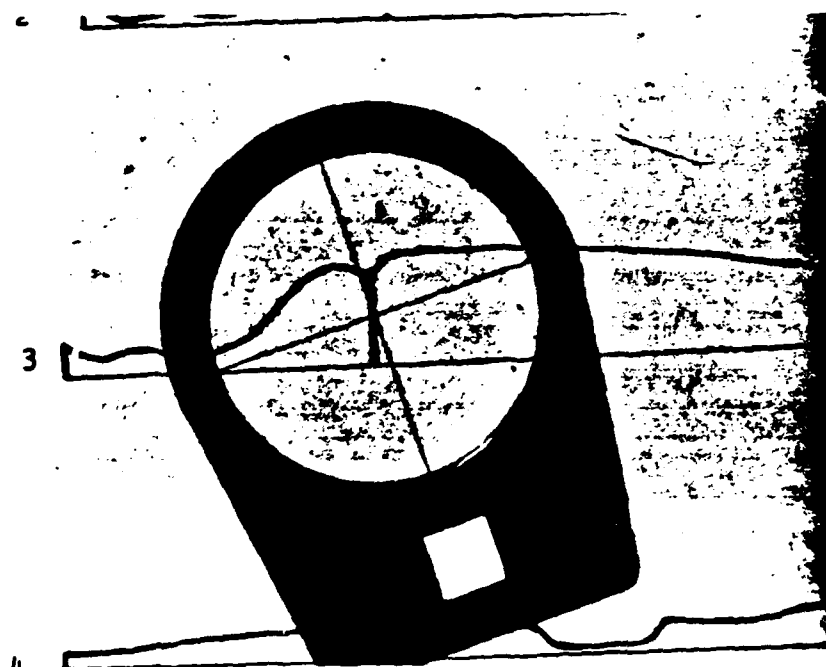
Data was collected and organized into five main categories: (1) facial margins; (2) lingual margins; (3) average margin from 0-250 microns along the shoulder; (4) average margin from 250-750 microns on the shoulder; and (5) average margin from 0-750 microns along the shoulder. Means were determined for each of the four groupings in each category. To evaluate the variation between each grouping, the standard deviation about the mean was calculated. A one-way analysis of variance was employed to examine the variation between the groups. A two-way analysis of variance was employed to determine if there was any interaction between the facial and lingual margins.

A post-hoc Duncan's multiple comparison test was performed to identify significant differences and rank the group means at a $p \leq .05$ level of significance.

IV. RESULTS

All raw data are contained in the Appendix. The means and standard deviations of the facial external margin, the lingual external margin, and the average internal margin gaps from 0-0.25 mm, from 0.25 mm-.75 mm, and from 0-0.75 mm on the shoulder are listed in Tables 1, 2, 3, 4 and 5, respectively.

The results of the two-way analysis of variance among the specimens' facial and lingual margins demonstrated a significant difference at the $p \leq .001$ level (Table 6). A post-hoc analysis (Duncan's multiple comparison test) at the $p \leq .05$ significant level demonstrated that the margins of the porcelain/liquid groups (A, C) were significantly smaller than those of the porcelain/wax groups (B, D). The post-hoc analysis demonstrated that there was no significant difference with the lingual margins among the four groups.

Upon comparing the average marginal opening along the first 0.25 mm of the shoulder, a significant difference ($p \leq .0062$) was noted. Table 7 contains the summary of the one-way analysis of variance. The Duncan's multiple comparison post-hoc analysis demonstrated the average gap of the porcelain/liquid group (A) with the metal to the shoulder was significantly smaller ($p \leq .05$) than that of the porcelain/wax group (D) with the metal off the shoulder. There was no statistical significance with the other two groups.

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Comparing the average marginal opening along the shoulder from 0.25 mm to 0.75 mm, a significant difference ($p \leq .0015$) was noted. The summary of the one-way analysis comparing this area is in Table 8. The Duncan's multiple comparison post-hoc analysis demonstrated that the porcelain/liquid group with the metal of the shoulder (C) was significantly ($p \leq .05$) larger in the average marginal gap than the other three groups.

When the average marginal opening was compared over 0 to 0.75 mm, a significant difference ($p \leq .0025$) was also noted. Table 9 has the summary of the one-way analysis of variance comparing this area. The Duncan's post-hoc analysis demonstrated that the porcelain/liquid group with the metal off the shoulder (C) was significantly ($p \leq .05$) larger in the average marginal gap than both groups with the metal on the shoulder (A, B). There was no statistical difference between Group C and Group D.

TABLE 1. EXTERNAL FACIAL MARGINS

GROUP	N	MEAN (MICRONS)	STANDARD DEVIATION
A (Porcelain/Liquid) (Metal to Shoulder)	15	27.48	13.73
B (Porcelain/Wax) (Metal to Shoulder)	15	49.31	10.97
C (Porcelain/Liquid) (Metal off Shoulder)	15	25.17	8.36
D (Porcelain/Wax) (Metal off Shoulder)	15	59.14	17.60

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TABLE 2. EXTERNAL LINGUAL MARGINS

GROUP	N	MEAN (MICRONS)	STANDARD DEVIATION
A (Porcelain/Liquid) (Metal to Shoulder)	15	10.72	4.28
B (Porcelain/Wax) (Metal to Shoulder)	15	15.52	7.31
C (Porcelain/Liquid) (Metal off Shoulder)	15	17.31	6.04
D (Porcelain/Wax) (Metal off Shoulder)	15	12.93	5.44

TABLE 3. AVERAGE MARGINAL OPENING FROM 0-0.25 mm
ON SHOULDER

GROUP	N	MEAN (MICRONS)	STANDARD DEVIATION
A (Porcelain/Liquid) (Metal to Shoulder)	15	24.12	10.37
B (Porcelain/Wax) (Metal to Shoulder)	15	31.76	7.24
C (Porcelain/Liquid) (Metal off Shoulder)	15	31.47	10.78
D (Porcelain/Wax) (Metal off Shoulder)	15	38.83	14.02

TABLE 4. AVERAGE MARGINAL OPENING FROM 0.25 mm TO
0.75 mm ON SHOULDER

GROUP	N	MEAN (MICRONS)	STANDARD DEVIATION
A (Porcelain/Liquid) (Metal to Shoulder)	15	40.28	18.64
B (Porcelain/Wax) (Metal to Shoulder)	15	39.53.	12.01
C (Porcelain/Liquid) (Metal off Shoulder)	15	67.90	32.33
D (Porcelain/Wax) (Metal off Shoulder)	15	47.21	15.99

TABLE 5. AVERAGE MARGINAL OPENING FROM 0 TO 0.75 mm
ON SHOULDER

GROUP	N	MEAN (MICRONS)	STANDARD DEVIATION
A (Porcelain/Liquid) (Metal to Shoulder)	15	34.88	14.67
B (Porcelain/Wax) (Metal to Shoulder)	15	36.91	9.59
C (Porcelain/Liquid) (Metal off Shoulder)	15	55.85	23.25
D (Porcelain/Wax) (Metal off Shoulder)	15	44.40	12.42

TABLE 6. SUMMARY TABLE FOR TWO-WAY ANALYSIS
OF VARIANCE COMPARING FACIAL AND
LINGUAL MARGINS

SOURCE	DF	SS	MS	F-value	F-probability
Class	1	20519.90	20519.90	198.56	.0001
Group	3	6192.96	2064.32	19.98	.0001
Interaction	3	6627.23	2209.08	21.38	.0001

TABLE 7. SUMMARY TABLE FOR ONE-WAY ANALYSIS
OF VARIANCE COMPARING THE AVERAGE
MARGINAL OPENING FROM 0 TO 0.25 mm

SOURCE	DF	SS	MS	F-value	F-probability
Group	3	1623.08	541.03	4.58	.0062
Error	56	6616.10	118.14		
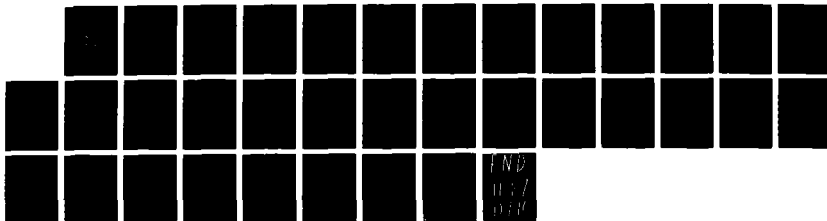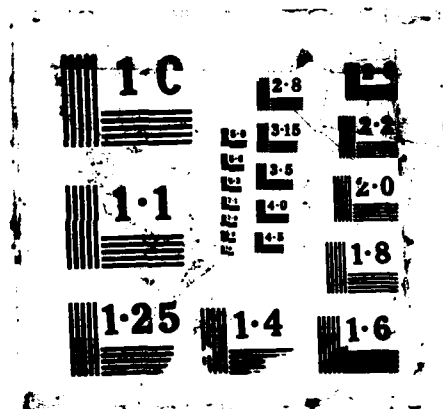
TABLE 8. SUMMARY TABLE FOR ONE-WAY ANALYSIS OF
VARIANCE COMPARING THE AVERAGE MARGINAL
OPENING FROM 0.25 mm TO 0.75 mm

SOURCE	DF	SS	MS	F-value	F-probability
Group	3	7888.70	2629.57	5.86	.0015
Error	56	25119.22	448.56		

TABLE 9.   SUMMARY TABLE FOR ONE-WAY ANALYSIS
            OF VARIANCE COMPARING THE AVERAGE
            MARGINAL OPENING FROM 0 TO 0.75 mm

SOURCE	DF	SS	MS	F-value	F-probability
Group	3	4049.68	1349.89	5.39	.0025
Error	56	14025.98	250.46		

V. DISCUSSION

Using standardized dies similar to teeth, castings of duplicate size and shape were produced in a unique fashion. A specially designed sculpturing device previously used to fabricate uniform porcelain specimens (Philp and Brukl, 1984) was modified to sculpture inlay wax on refractory investment dies. The utilization of refractory investment dies eliminated or minimized potential distortion: (1) during pattern withdrawal from the die; (2) from a temperature difference between wax pattern and investment material; (3) from incorporation of voids inside the pattern during investing; (4) from improper positioning of the wax pattern inside the ring; and (5) from variation in burnout temperature (Baum and McCoy, 1984).

To further eliminate any potential source of variation in the specimens due to casting variables, acrylic resin was directly poured into the castings to form the working dies. It is accepted that acrylic resin shrinks upon polymerization; however, this fact did not affect this study. In a similar experimental protocol, Gavelis et al. (1981) found upon microscopic evaluation no shrinkage spaces between the die and the internal surface of the crown. Shrinkage did occur, but it was limited to the open end of the boxed castings, thus causing the formation of a meniscus.

A major concern in the fabrication of the porcelain facial margin is expressing a small amount of porcelain slurry beneath the metal coping during vibration and condensation. This misplaced material can result in the restoration tipping lingually or preventing its complete seating. Though this porcelain can be removed after firing, it can result in an improved fit of the facial margin and a diminished fit of the lingual. With the close tolerance of fit between the metal copings and working dies in this study, movement of this type caused by any of the four techniques under investigation would be apparent. This type of problem was anticipated for the porcelain/liquid group with the metal off the shoulder, as porcelain slurry readily seeped beneath the unprotected axial wall during condensation.

Statistical analysis did not reveal any significant differences between any of the four groups. This result confirms the recent investigation of Wanserski et al. (1986) which found that clinically acceptable metal coping margin adaptation can be preserved during fabrication of the all-porcelain labial margin. This result credits the importance of using a stereomicroscope between porcelain firings to remove minute areas of fused porcelain beneath the metal copings, a technique repeatedly performed in this investigation.

Statistical analysis revealed that the margins of the porcelain/liquid groups (27.48 and 25.17 microns) were significantly smaller than those of the porcelain/wax groups (49.31 and 59.14 microns). Only one previous investigation

(Cooney et al., 1985) has compared the fit of porcelain/liquid and porcelain/wax margins and under the conditions of that study, no significant differences were found. A possible explanation of this result might be due to the large marginal opening (72 microns) they obtained with their porcelain/liquid technique, which they stated was due to rounding of the margin. Microscopic observation of the four groups in this current investigation revealed those fabricated with the porcelain/liquid technique maintained their sharp integrity during porcelain firing. Those fabricated using the porcelain/wax technique were rounded over the outer 100 microns of the margin. This rounding of the porcelain/wax in a 6:1 ratio was noted by Gordner (1986) in the fabrication of his samples and by Cooney et al. (1985) in his restorations, even though he used a higher ratio (7:1).

Several recommendations as to which ratio of porcelain/wax by weight to use are described in the literature. Prince et al. (1983), Donovan et al. (1985), and Howard (1985) recommended a 6:1 porcelain/wax ratio; Cooney et al. (1985) and Schrader (1986) recommended a 7:1 ratio; and Wiley et al. (1986) recommended a 8:1 ratio. Gordner's (1986) recommendation of a 6:1 porcelain/wax mixture is based upon research rather than handling characteristics and empirical logic. When various porcelain/wax ratios were compared, the 6:1 ratio displayed the least surface irregularity and a significantly higher transverse rupture strength. Employing the 6:1 ratio minimized the advantage of decreased shrinkage

yielded by higher ratios; however, it still yielded a 7.35% decrease in shrinkage compared to the conventional modeling liquid technique.

Gordner also observed that certain groups in his investigation had an actual increase in their height dimension, however, he could not offer an explanation. Considering dental waxes have the largest coefficient of thermal expansion of any material used in restorative dentistry (Craig, 1985), is a possible explanation to this phenomenon and why an excessive rounding of the margin occurs. When the porcelain/wax mixture is placed beneath the muffle of the oven, an expansion of the mixture may produce a loss of margin sharpness which is non-recoverable. This phenomenon may also account for the decreased shrinkage with the porcelain/wax technique as the porcelain particles are in an expanded state when the sintering process is initiated. The margin technique using porcelain/liquid does not go through this initial expansion and does not interfere with the shoulder porcelain's higher resistance to pyroplastic flow.

The significance of this external rounding is important. The change in external line contour may produce a stagnation area, allowing food debris and bacteria to buildup, with probable adverse effects on the gingival tissue. Hunt et al. (1978) and West et al. (1985) addressed this problem in their measurement of porcelain specimens. Both chose to measure their marginal openings at locations internal to the area where the first effects of marginal rounding could be

detected and did not provide any information on the rounded external area. Cooney et al. (1985) also addressed the problem of rounding in their specimens, but did not furnish enough information describing where they initiated their measurements. Failure to include information on this area in any investigation could make the overall results appear significantly better than they actually are.

Due to the difficulty in obtaining a single point of measurement in this area in the present study, three readings were made in all margins that were rounded. These points were at the external margin of the die, 50 microns internal, and 100 microns internal where the effects of the external rounding were no longer visible. This allowed for a composite margin area by averaging these three readings to reflect a more accurate representation of this area than has been previously described.

One of the main advantages of the porcelain/wax technique is its relative simplicity (Prince and Donovan, 1983) and this was also true in this investigation. The problem of lifting the green porcelain off the die was considerably easier with the wax binder than with the liquid binder technique. The porcelain/wax technique also eliminated the problem of porcelain slurry seeping beneath the metal coping causing tipping or preventing the seating of the restoration. To investigate whether the porcelain/wax technique allowed better adaptation of the sintered porcelain to the die shoulder, the mean marginal openings were computed with the aid of a

Zeiss Interactive Digital Analysis Sytem (ZIDAS). Three areas were computed with this system for all four groups: (1) from the external margin to 0.25 mm internal on the shoulder; (2) from 0.25 to 0.75 mm on the shoulder; and (3) from the external margin to 0.75 mm internal on the shoulder.

Results from the region of the external margin to 0.25 mm internal showed only a significant difference between the porcelain/liquid technique with the metal on the shoulder (24.12 microns) and the porcelain/wax technique with the metal off the shoulder (38.83 microns). This result can probably be explained on the basis that more porcelain/wax material was needed in this technique to fill the residual margin gap after initial margin buildup. The increase in amount of porcelain/wax paste resulted in a slightly larger marginal gap due to the rounding which occurred during its firing.

Results over the internal region of 0.25 mm to 0.75 mm revealed the porcelain/liquid technique with the metal off the shoulder had a significantly greater opening than the other three techniques. This can be attributed to the difficulty in getting the porcelain slurry to flow into small marginal gaps without disturbing the film of separating medium present. The technique which had the metal brought down to the shoulder did not require porcelain to seep as far in on the shoulder and probably was easier to fill. The porcelain/wax technique did not have a problem with the residual liquid and would more readily flow into the small marginal gaps. The importance of this internal area may be questionable;

however, if the small outer marginal area reflects unsupported porcelain, a potential for fracture exists. This fracturing of unsupported porcelain could occur during clinical try-in of the restoration or during cementation due to the hydraulic force of the cementing medium.

Considering the overall margin from the external area to 0.75 mm internal, a significant difference between both techniques with the metal brought down to the shoulder (34.88 and 36.01 microns) and the porcelain/liquid technique with the metal 0.5 mm off the shoulder (55.85 microns) was observed. There was no significant difference between the two techniques with the metal off the shoulder. If the internal fit of porcelain is considered to be important, then the lifting of the metal coping off the margin may not be a viable alternative. This modification of coping design may have developed to allow for inadequate tooth reduction at the margin area. Without a matrix to lift the green porcelain off the die, more of the opacious shoulder porcelain is required on the axial wall of the coping. This in itself can negate the esthetic advantage of having less metal in the area due to the color mismatch between the body and shoulder porcelain.

Examining the results regarding both external marginal seal and internal marginal adaptation, the porcelain/liquid technique with the metal brought down to the shoulder was statistically superior to the other three groups. Though the porcelain/wax technique was a much simpler one to employ, the excessive rounding of the external area reduced the

effectiveness of having a porcelain that is resistant to pyroplastic flow. There may be certain instances when the porcelain/wax technique may be the one of choice, such as margin areas which contain undercuts and do not allow porcelain to be lifted from the margin without crumbling or in cases of multiple splinted abutments with fixed partial dentures.

The design of this study looked at two of the most common direct-lift techniques for fabricating porcelain margins. Additional studies should include: (1) a material study on how light-cured resins would function as a medium for transporting porcelain; (2) if the use of an investment liquid (Vestra, Unitek Corp., Moncovia, CA) as described by Kessler et al. (1986) offers any advantages over that of a conventional modeling liquid; (3) if a wax overlay method of fabricating margins as described by Hurtado (1986) offers any advantage to a porcelain/wax paste; (4) do any of the current techniques result in a porcelain labial margin that is more or less prone to fracture than any other; and (5) would the modified technique of using porcelain/wax on the internal aspect of the shoulder and porcelain/liquid on the external area produce a superior margin.

VI. SUMMARY

This investigation was designed to examine the marginal characteristics of the collarless metal-ceramic restoration fabricated with two commonly used direct-lift techniques: a porcelain/wax paste and a porcelain/liquid slurry. The metal copings were touching the shoulder in one half of the groups and left 0.5 mm short of the shoulder in the other half to comprise the four experimental groups. Marginal seal was evaluated at facial and lingual areas on embedded, sectioned specimens for each group. Photonegatives were made of each specimen and projected at a constant magnification to allow tracings to be fabricated of the space between the die shoulder and the corresponding porcelain. Composite area measurements were made for each sample with a Zeiss Interactive Digital Analysis System to evaluate porcelain adaptation to the shoulder. The following results and conclusions can be drawn from this investigation:

1. The porcelain/liquid groups demonstrated significantly smaller facial marginal gaps than the porcelain/wax groups ($p \leq .05$).

2. The porcelain/liquid technique demonstrated sharp and distinct external margins, whereas those fabricated with the porcelain/wax technique were rounded over a 100 micron distance.

3. Porcelain adaptation to the shoulder was significantly better ($p \leq .05$) over the initial 0.25 mm of the shoulder with the porcelain/liquid group with the metal to the shoulder than with the porcelain/wax group with metal off the shoulder.

4. The porcelain/liquid group with the metal off the shoulder had a statistically larger mean marginal opening ($p \leq .05$) from 0.25 mm to 0.75 mm on the internal aspect of the shoulder than the other three experimental groups.

5. The porcelain/liquid group with the metal off the shoulder had a statistically larger mean marginal opening ($p \leq .05$) from the external margin to 0.75 mm internal on the shoulder than both techniques with the metal to the shoulder.

6. The group fabricated with the porcelain/liquid technique with metal to the shoulder produced the most consistent overall results.

7. Lingual marginal adaptation did not vary with each of the four experimental groups.

8. The results of this investigation would caution the use of the porcelain/wax technique and leaving the metal coping short of the shoulder in fabricating porcelain margins.

APPENDIX

RAW DATA FOR TEST SPECIMENS

TABLE 1A.   SUMMARY TABLE FOR FACIAL MARGINS
IN MICRONS

Specimen	Group A (P/L, M to S)	Group B (P/W, M to S)	Group C (P/L, M off S)	Group D (P/W, M to S)
1	12.7	59.6	16.3	50.6
2	39.0	50.2	21.3	41.0
3	15.0	50.0	30.3	106.0
4	26.3	55.6	11.3	79.3
5	30.0	54.6	25.0	50.7
6	38.7	64.2	32.0	72.0
7	58.7	41.0	30.0	47.7
8	43.3	43.1	35.0	41.0
9	16.3	31.3	36.0	50.4
10	13.3	69.3	20.0	69.9
11	37.3	46.4	14.3	46.0
12	25.7	40.0	36.3	57.2
13	27.3	40.7	15.7	61.3
14	15.3	58.6	30.0	45.7
15	13.3	35.1	24.0	68.3

TABLE 2A. SUMMARY TABLE FOR LINGUAL MARGINS
IN MICRONS

Specimen	Group A (P/L, M to S)	Group B (P/W, M to S)	Group C (P/L, M off S)	Group D (P/W, M off S)
1	8.7	13.3	32.0	17.0
2	13.7	7.7	12.3	0.0
3	9.3	9.7	11.0	18.0
4	11.0	27.0	25.3	21.3
5	12.0	6.7	13.0	9.7
6	12.0	12.7	10.3	12.7
7	9.7	15.3	13.6	14.7
8	8.7	31.7	19.7	15.3
9	7.3	14.7	17.7	21.0
10	7.3	10.3	15.7	10.3
11	12.7	21.0	21.0	11.3
12	23.7	11.7	20.7	7.0
13	10.3	24.7	20.0	11.0
14	9.7	12.3	10.7	13.0
15	4.7	14.0	16.7	11.7

TABLE 3A. MARGIN SUMMARY FOR GROUP A
(PORCELAIN/LIQUID WITH METAL
TO SHOULDER) IN MICRONS

Specimen	Facial	Lingual
1	13,14,11	7,9,10
2	38,38,41	13,13,14
3	15,14,16	10,8,10
4	25,28,26	13,10,10
5	28,31,31	12,13,11
6	38,38,40	13,10,13
7	58,58,60	10,10,9
8	42,46,42	10,6,10
9	14,18,17	7,9,6
10	11,12,14	7,9,6
11	38,38,36	12,13,13
12	24,28,25	23,25,23
13	29,25,28	9,11,11
14	16,16,14	10,9,10
15	13,14,13	4,5,5

TABLE 4A. MARGIN SUMMARY FOR GROUP B
(PORCELAIN/WAX WITH METAL
TO SHOULDER) IN MICRONS

Specimen	external	Facial at 50 microns	at 100 microns	Lingual
1	89,93,95	58,57,54	28,30,32	14,12,15
2	91,96,91	42,46,45	15,14,12	7,8,8
3	84,90,86	41,35,34	25,28,27	9,9,11
4	82,83,85	52,53,50	32,33,30	27,27,27
5	90,87,90	48,47,49	27,27,27	6,7,6
6	113,112,115	42,45,41	35,37,37	13,13,11
7	*	42,39,42	*	15,18,13
8	82,82,79	33,22,35	13,16,16	33,30,32
9	44,47,45	26,30,30	17,21,22	17,14,13
10	117,114,116	53,57,56	35,37,39	10,12,9
11	82,84,88	33,38,33	18,20,21	21,22,20
12	*	42,36,41	*	12,11,12
13	60,57,61	36,37,38	28,25,23	25,26,23
14	100,105,103	40,40,43	28,30,39	11,13,13
15	56,52,53	30,28,29	21,22,25	13,14,15

(*Specimens 7 and 12 were not rounded.)

TABLE 5A.   MARGIN SUMMARY FOR GROUP C
            (PORCELAIN/LIQUID WITH METAL
            OFF SHOULDER) IN MICRONS

Specimen	Facial	Lingual
1	17,17,15	32,31,33
2	20,21,23	9,15,13
3	29,30,32	21,20,22
4	9,13,12	22,27,27
5	28,23,24	15,10,14
6	35,30,31	9,10,12
7	29,32,29	15,14,12
8	35,34,36	19,19,20
9	36,38,34	19,15,18
10	19,18,23	15,17,15
11	13,14,16	21,23,19
12	37,35,37	21,19,22
13	14,19,14	20,22,18
14	28,30,32	12,10,10
15	23,26,23	18,17,15

TABLE 6A.   MARGIN SUMMARY FOR GROUP D
(PORCELAIN/WAX WITH METAL
OFF SHOULDER) IN MICRONS

Specimen	external	Facial at 50 microns	at 100 microns	Lingual
1	85,88,86	39,36,37	26,30,28	18,18,15
2	70,73,71	37,37,34	14,18,15	0,0,0
3	170,172,168	102,100,102	44,48,48	18,20,16
4	137,140,134	69,63,64	35,37,35	21,23,20
5	104,108,107	30,33,29	14,16,15	10,9,9
6	*	72,70,74	*	12,13,13
7	92,90,91	37,38,34	14,18,15	14,15,15
8	58,64,62	37,40,39	24,20,25	17,16,14
9	70,67,72	49,50,47	33,34,32	21,19,23
10	105,103,107	66,65,66	37,40,40	10,12,9
11	*	46,44,48	*	13,11,10
12	103,100,105	41,44,43	28,25,26	8,6,7
13	*	63,61,60	*	13,10,10
14	80,80,80	33,35,35	25,21,23	12,15,12
15	83,89,87	64,63,65	53,57,54	10,12,12

(*Specimens 6, 11, and 12 were not rounded.)

TABLE 7A. SUMMARY TABLE FOR ZIDAS MEASUREMENTS
GROUP A (PORCELAIN/LIQUID WITH METAL
TO SHOULDER)

Specimen	0-0.25 mm		0.25 mm-0.75 mm		0-0.75 mm	
	ZIDAS Value	Average Micron Opening	ZIDAS Value	Average Micron Opening	ZIDAS Value	Average Micron Opening
1	119.3	14.0	347.8	20.4	467.1	18.3
2	118.3	13.8	390.4	22.9	508.7	19.9
3	314.0	36.8	1360.0	77.1	1674.0	63.7
4	175.0	20.5	436.8	25.6	611.8	23.9
5	228.0	26.7	557.3	32.6	785.3	30.6
6	301.6	35.3	1166.0	68.3	1467.6	57.3
7	143.1	16.7	244.4	14.3	387.5	15.1
8	376.3	44.1	839.4	49.2	1215.7	47.5
9	212.1	24.8	666.0	39.0	878.1	34.2
10	129.1	15.1	774.0	45.3	903.0	35.2
11	251.2	29.4	675.8	39.6	927.0	36.2
12	136.1	15.9	828.2	48.5	964.3	37.6
13	325.9	38.2	797.8	46.7	1123.7	43.8
14	118.7	13.9	988.9	57.9	1107.6	43.2
15	141.8	16.6	287.5	16.8	429.3	16.7

TABLE 8A.   SUMMARY TABLE FOR ZIDAS MEASUREMENTS
GROUP B (PORCELAIN/WAX WITH METAL
TO SHOULDER)

| Specimen | 0-0.25 mm | | 0.25 mm-0.75 mm | | 0-0.75 mm | |
	ZIDAS Value	Average Micron Opening	ZIDAS Value	Average Micron Opening	ZIDAS Value	Average Micron Opening
1	310.7	36.4	636.8	37.3	947.5	37.0
2	174.4	20.4	415.2	24.3	589.6	23.0
3	367.6	43.0	932.0	54.6	1299.6	50.7
4	317.3	37.2	993.6	58.2	1310.9	51.2
5	275.4	32.3	345.2	20.2	620.6	24.2
6	287.8	33.7	556.0	32.6	843.8	32.9
7	299.2	35.1	651.7	38.2	950.9	37.2
8	215.8	25.3	611.9	35.8	827.7	32.3
9	248.3	29.1	424.1	24.8	672.4	26.2
10	338.9	39.7	769.2	44.7	1108.1	43.0
11	298.4	34.9	653.3	38.3	951.7	37.1
12	223.8	26.2	770.8	45.1	994.6	38.8
13	336.5	39.4	1042.0	61.0	1378.5	53.8
14	198.4	23.2	752.8	44.1	951.2	37.1
15	174.9	20.5	574.6	33.7	749.5	29.3

TABLE 9A. SUMMARY TABLE FOR ZIDAS MEASUREMENTS
GROUP C (PORCELAIN/LIQUID WITH METAL
OFF SHOULDER)

Specimen	0-0.25 mm		0.25 mm-0.75 mm		0-0.75 mm	
	ZIDAS Value	Average Marginal Opening	ZIDAS Value	Average Marginal Opening	ZIDAS Value	Average Micron Opening
1	319.3	37.4	627.2	36.7	946.5	36.9
2	245.5	28.8	1699.0	99.5	1944.5	75.9
3	128.0	15.0	694.0	40.7	822.0	32.1
4	377.2	44.2	1643.0	96.2	2020.2	78.9
5	231.3	27.1	586.8	34.4	818.1	32.0
6	289.2	33.9	2148.0	125.8	2437.2	95.2
7	224.4	26.3	1916.0	112.2	2140.4	83.6
8	226.0	26.5	1018.0	59.6	1244.0	48.6
9	245.8	28.7	1257.0	73.6	1502.8	57.9
10	309.1	36.2	981.5	57.5	1290.6	50.4
11	527.0	61.7	1749.0	102.4	2276.0	88.8
12	206.8	24.2	454.7	26.6	661.5	25.8
13	196.9	23.1	686.0	40.2	882.9	37.5
14	244.6	28.8	1250.0	73.2	1494.6	58.4
15	257.0	30.1	682.0	39.9	93.9	36.6

TABLE 10A. SUMMARY TABLE FOR ZIDAS MEASUREMENTS
GROUP D (PORCELAIN/WAX WITH METAL
OFF SHOULDER)

Specimen	0-0.25 mm		0.25 mm-0.75 mm		0-0.75 mm	
	ZIDAS Value	Average Micron Opening	ZIDAS Value	Average Micron Opening	ZIDAS Value	Average Micron Opening
1	286.9	33.6	519.9	30.5	806.8	31.5
2	255.5	29.9	315.9	18.5	571.4	22.3
3	442.6	51.9	597.5	35.0	1040.1	40.6
4	541.7	63.5	827.7	48.5	1369.4	53.5
5	269.1	31.5	612.6	35.9	881.7	34.4
6	255.9	30.0	746.6	43.7	1002.5	39.1
7	178.7	20.9	577.2	33.8	755.9	29.5
8	259.9	30.4	1109.0	65.0	1368.9	53.5
9	447.9	52.5	686.9	40.2	1134.8	44.3
10	376.8	44.1	1062.0	62.2	1438.8	56.1
11	562.5	65.9	972.3	57.0	1534.8	60.0
12	254.2	29.8	728.4	42.7	982.6	38.4
13	215.6	25.3	1101.0	64.5	1316.6	51.4
14	247.1	28.9	890.7	52.2	1137.8	44.4
15	377.4	44.2	1339.0	78.4	1716.4	67.0

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He accepted a commission in the United States Air Force in 1978 and was assigned to Castle AFB, Merced, California. An assignment to Dover AFB, Dover, Delaware followed in 1982.

In July, 1984, he entered The University of Texas Health Science Center at San Antonio, Texas for the Post-Doctoral Prosthodontic Program. In 1985, he was admitted as a candidate for the Master of Science Degree at the Graduate School of Biomedical Sciences. He received a certificate in Prosthodontics in June, 1987.

He has been assigned the position as Assistant Chief of Prosthodontic Services at Eglin AFB, Florida and will assume that position in August, 1987.

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